

UTILITY APPLICATION

OF

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FOR

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ON

3-D ADAPTIVE LASER POWDER FUSION WELDING

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3-D ADAPTIVE LASER POWDER FUSION WELDING

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Cross-References to Related Applications

This patent application is related to, but claims no priority from, United States Patent Number 10/071,025 filed 2/08/2002 for Hand Held Laser Powder Fusion Welding Torch and United States Patent Number 10/206,411 filed 7/26/2002 for Powder Feed Splitter for Hand-Held Laser Powder Fusion Welding Torch, which are incorporated by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to Laser Powder Fusion Welding (LPFW) Systems and more particularly to a platform system for a Laser Powder Fusion Welding System enabling the workpiece to be disposed with respect to the laser head according to the six usual axes (roll, pitch, yaw, and x, y, z) as well as a teaching tool in order to affect repair and to provide three-dimensional data entry for the laser welding head.

Description of the Related Art

In the past, developments regarding Laser Powder Fusion Welding (LPFW) have been on a primitive or preliminary basis. Generally, the workpiece is held stationary while a moveable LPFW head is then applied in order to construct, fabricate, or repair the workpiece. In some circumstances, the table or platform upon which the workpiece rests may be rotated and the workpiece constructed or worked upon in the manner of a potter's wheel or similar.

Such geometrical disposition between the generally stationary workpiece and the moveable LPFW head constrains the types of articles that can be fabricated and/or repaired by the LPFW head. Certain angles and dispositions between the workpiece and LPFW head more readily accommodate the specific geometries of the workpiece and may enable better LPFW head functioning and performance in order to achieve the goals of the LPFW process. Current

means do not allow for significant workpiece manipulation for engagement by the LPFW head or significant LPFW head manipulation for workpiece engagement.

LPFW Welding is particularly advantageous for certain materials that are not readily welded by other means. Components needing LPFW often exhibit variation from nominal surface contours in excess of what the welding process will tolerate. This causes or may lead to a higher probability of defect rates or the inability to use LPFW at all unless the components are machined prior to welding in a manner that minimizes such variation. Such additional operations increase cost due to the added labor and material. They also increase the time it takes to operate on the workpiece.

Currently, there are no machines or processes available to adapt to multi-dimensional part variability. It is generally well known that most high temperature super alloys (including those with refractory metals) are defined as “non-weldable” by conventional welding methods. Existing laser welding systems do not have the capability to trace and program a complex geometry for a part in a manner that positions the laser normal to the surface in a constant fixed distance during LPF (Laser Powder Fusion) welding.

In view of the foregoing, there is a need for providing an LPF system that can engage a dimensionally-variable part for both welding and tracing. Such a system could provide for greater reliability in part repair and enable LPF welding to be applied to super alloys or refractory materials.

SUMMARY OF THE INVENTION

In view of the foregoing disadvantages, the 3-D adaptive laser powder fusion welding system set forth herein provides means by which multi-dimensional parts can be traced for welding and welded despite significant variability in the part's geometry. Additionally, beyond the tracing function which enables a three-dimensional modeling of a part, laser powder fusion (LPF) welding can then be applied to a part that departs from a model that has either been traced before or is otherwise available as a model.

By bringing LPF welding to bear upon such variable geometry parts, the use of refractory materials or super alloys may become more readily available as the barriers to use of such materials that arise from their “unweldable” nature by conventional means is overcome by the use of LPF welding.

The 3-D adaptive laser powder fusion welding system set forth herein provides means by which a model parts can be traced and archived for future reference. Such archiving of models occurs in a 3-D representation in an information storage device, such as a computer.

Additionally, Laser Powder Fusion Welding (LPFW) is achieved by a laser welding head. A staging apparatus enables articulation of a workpiece in the six classical axes: x, y, and z as well as roll, pitch, and yaw. Consequently, the three spatial and three angular axes are enabled so that the laser powder fusion welding head can perform laser powder fusion welding activities on the workpiece. The stage also provides means by which the laser range finding head can perform its tracing and archiving functions.

By providing such a system, "golden" parts can be imaged, modeled, or otherwise archived to memory. Once modeled electronically or digitally, the electronic model representation can then be transmitted to other laser powder fusion welding systems so that repairs and operations can be performed anywhere according to a model that may also be archived locally or far away, even on another continent. In fact, a high-resolution tracing center for parts could provide the electronic templates for worldwide manufacture and repair.

By providing such a system, manufacture, alteration, and repair of parts that are subject to laser powder fusion welding are readily and easily achieved. Furthermore, those materials which are generally not subject to regular welding processes are now opened up for commercial and technical exploitation due to the removal of the prior obstacle of not being susceptible to normal welding processes.

In one embodiment, the 3-D adaptive laser powder fusion welding system subjects a workpiece to laser powder fusion welding via a laser head system and a linear displacement element coupled to the laser head and enabling the laser head to be displaced linearly in a first dimension. A support apparatus holds the workpiece adjacent the laser head in an adjustable and selectable manner and provides five degrees of freedom for the workpiece in second and third linear dimensions and first, second, and third rotational dimensions. In this way; the laser head may engage the workpiece about its exterior. By so engaging the workpiece, the welding system enables welding to occur at almost any, if not every, surface of the workpiece.

In another embodiment, the 3-D adaptive laser powder fusion welding system subjects a workpiece to laser powder fusion welding via a laser head system that includes a laser welding head, a powder feed delivery system, and a tracing system that determines the topology of the workpiece. A linear displacement element coupled to the laser head enables the laser head to be displaced linearly in a first dimension and a support apparatus holds the workpiece adjacent the laser head in an adjustable and selectable manner. The support apparatus provides five additional degrees of freedom for the workpiece in second and third linear dimensions and first, second, and third rotational dimensions. The support apparatus including an x-axis prismatic element enabling linear travel along a first linear axis, a y-axis prismatic element enabling

linear travel along a second linear axis, a roll revolute element enabling angular travel centered upon a roll axis, a pitch revolute element enabling angular travel centered upon a pitch axis, a yaw revolute element enabling angular travel centered upon a yaw axis. The x-axis, y-axis, roll revolute element, pitch revolute element, and yaw revolute elements are coupled to one another.

5 A filler delivery system providing filler material to the laser head system. A laser supplying laser light to the laser head system is included and may generally rely upon an Nd-YAG laser. Alternative sources of laser energy may also be used, including lasers based on or using carbon dioxide (CO₂) and/or ~~yttrium~~ ^{Ytterbium} fiber diode laser systems. A controller system controls operation of the filler delivery system, the laser, the laser head system, the linear displacement element, and the support apparatus. The controller system includes: a digital servo amplifier system
10 coupled to the support apparatus and controlling operation of the five degrees of freedom; a robot controller coupled to and controlling the laser head system, the linear displacement element, and the digital servo amplifier; and a computer programmably operating the robot controller and enabling recording of data through the controller system. The 3-D LPF system is
15 able to engage the workpiece about an exterior of the workpiece and by so engaging the workpiece, the welding system enables welding to occur at almost any, if not every, surface of the workpiece.

Other features and advantages of the present invention will become apparent from the following description of the preferred embodiments taken in conjunction with the accompanying drawing which illustrates, by way of example, the principles of the system set forth herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a schematic diagram of the 3-D adaptive laser powder fusion welding system set forth herein with the central positioning table and related welding equipment being generally circumscribed in schematic form by control and communication elements.

Figure 2 is an enlarged portion of Figure 1 as designated by the dashed box in Figure 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

30 The detailed description set forth below in connection with the appended drawings is intended as a description of presently-preferred embodiments of the invention and does not represent the only forms in which the present invention may be constructed and/or utilized. The description sets forth the functions and the sequence of steps for constructing and operating the invention in connection with the illustrated embodiments. However, it is to be understood that

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the same or equivalent functions and sequences may be accomplished by different embodiments that are also intended to be encompassed within the spirit and scope of the invention.

The 3-D adaptive laser powder fusion welding system **100** has a central table or platform **102** upon which geometrical control elements (generally indicated as **104**) operate in order to dispose a workpiece **W** in relation to either a laser powder fusion welding head **106** or a laser rangefinder head **108**. The geometrical control elements **104** generally control five of the six available axes as used herein, these axes are the three lateral axes generally known in the art as x, y, and z that define a three-dimensional space as well as the three rotational axes commonly known as roll, pitch, and yaw. The geometrical control elements **104** associated with the table **102** operate to control the three rotational and the two lateral, x and y, directions of linear displacement. The third axis of linear displacement is controlled by the height at which either the LPFW head **106** or laser rangefinder **108** are disposed with respect to the workpiece **W**.

Generally the linear components are those of high precision and are generally known in the art. As indicated in Figure 1, the term “prismatic” generally indicates linear directions of travel. The term “revolute” indicates an angular displacement control. For the prismatic/linear elements to the geometrical controls **104**, high precision servomotors and the like can be used in order to precisely and accurately control the linear travel of the support apparatus **110**. The support apparatus includes the geometrical control elements as well as any intermediating support elements that serve to displace one geometrical control element from another.

Similarly, high precision and high accuracy servomotors may serve to provide angular displacement for the revolute elements in the system **100**. Similar to the prismatic elements associated with the support apparatus **110**, prismatic element may also be used in conjunction with the laser heads **106**, **108**.

Turning now to the details of the table **102**, the set of axes **120** are shown both in association with the table **102** and the workpiece **W**. These axes define similar geometries and are assumed to be identical save for the lateral displacement between the origin of the two. Consequently, use of the terms x, y, and z axes as well as roll, pitch, and yaw are generally relative to the axes **120** shown in Figure 1. Roll is generally considered to be movement around the x-axis or a roll axis, pitch is motion rotating generally upon the y-axis or pitch axis, while yaw is angular motion rotating generally upon the z-axis or yaw axis. The definition of these rotational axes may be relative to the workpiece **W** as opposed to the table **102**.

On the table **102**, a first linear displacement element **130** is shown supported above the surface of the table **102** by a post or other support **132**. The linear displacement element for the x-axis **130** is also indicated in the drawing Figure 1 as “J1 Prismatic”. The x-axis linear

displacement element **130** travels along a rod, screw, path, or otherwise in a manner parallel to the x-axis **120** generally along one side of the table **102**. This leaves the rest of the table space available for motion along the y-axis **120**. While not shown in Figure 1 for drawing purposes, the x-axis linear displacement element **130** travels above the surface of the table as held by the rod or otherwise. The same is similarly true for the other elements of the support apparatus **110** with its geometrical control elements **104**.

Coupled to the x linear displacement element **130** is a y linear displacement element **136** which is also indicated in Figure 1 as “J2 Prismatic”. In a manner similar to that for the x-axis linear displacement element **130**, the y-axis linear displacement element **136** travels parallel to the y-axis **120** in the same way that the x linear displacement element **130** travels parallel to the x-axis **120**. The x and y linear displacement elements **130**, **136** may have a total possible distance of travel along predefined paths of a certain length designated in Figure 1 as L1. This generally defines a square area having sides of equal length and right angles to each other on which the workpiece **W** may travel. L1 may be an arbitrarily chosen distance for the types of workpieces **W** to be handled in the system **100** set forth herein. Alternatively, such distances may be different for the x linear displacement element **130** and the y linear displacement element **136**. If the x and y available travel distances are not equal, the resulting area defined by the x and y linear displacement elements **130**, **136** is a rectangle.

With the foundational definition of x-axis and y-axis degrees of freedom for the workpiece **W** via the x and y linear displacement elements **130**, **136**, additional rotational elements provide angular control for roll, pitch, and yaw axis for the workpiece **W**.

Separated from the y linear displacement element **136** by an appropriately chosen distance L2, a yaw control **140** (J4 Revolute) enables the workpiece **W** to enjoy angular displacement about the z-axis **120**. Similarly, a pitch control **142** (J5 Revolute) provides angular displacement with respect to the y-axis **120**. The pitch control **142** may be separated from the yaw control **140** by a distance L4.

A roll control element **144** (J6 Revolute) may control rotational displacement about the x-axis. The workpiece study of itself may be coupled to the roll control **144** by means of a support having a distance L6 or otherwise.

Note should be taken, that the distances between the y linear displacement element **136** and the yaw, pitch, and roll elements **140**, **142**, **144** may also be variable in distance such that distances L2, L4, L5, and L6 may be varied according to pre-selected and adjustable distance controls.

From the foregoing, it can be seen that the disposition of the workpiece **W** is controlled in

generally five dimensions: two linear (x and y) and three angular (roll, pitch, and yaw). In order to provide for control over the sixth axis, namely displacement along the z-axis **120**, z linear displacement element **150** (J3 Prismatic) is coupled to both the laser powder fusion welding head **106** and the laser rangefinder head **108** as the two laser heads, **106**, **108** are disposed in a generally perpendicular manner to the z-axis linear displacement element **150** and so generally always enjoy the same height above the table **102**.

The z-axis linear displacement element may be coupled to a structure or support that is coupled to the table **102**. For purposes of visual depiction, a post **152** is shown connected to a background substrate which gives ultimate support to the laser heads **106**, **108**.

The laser heads **106**, **108** are significantly different in nature. The laser powder fusion welding head **106** is significantly energetic in order to melt a number of materials including plastics and metals. Consequently, the LPF welding head **106** is much more industrial in nature as it needs to resiliently withstand the dynamic and generally hostile environment that arises from laser powder fusion welding. As indicated in Figure 1, the LPF Welding head **106** may be powered by an Nd-YAG (neodymium-yttrium-aluminum garnet) laser **160** which provides sufficient power to the LPF head **106** in order to meld, melt and/or weld the materials used thereby. Alternative sources of laser energy may also be used, including lasers based on or using carbon dioxide (CO₂) and/or yttrium fiber diode laser systems. Such material is delivered by a filler material delivery system **162** which may be operated in accordance with the needs and demands of the workpiece **W** and the welding thereof by the LPF Welding head **106**. The same is similarly true for the laser **160** where the energy arising from the laser **160** is selectably controllable in order to provide better and more adjustable welding for the workpiece **W**.

Laser **160** and filler material delivery systems **162** are known in the art but may also be derived from previously filed patent applications assigned to the same assignee as the present technology. U.S. patent application serial number 10/071,025 filed on February 8, 2002 entitled Hand-Held Laser Powder Fusion Welding Torch by Baker et al. is incorporated by reference. United States Patent Application Serial Number 10/206,411 filed July 26, 2002 for a Powder Feed Splitter for Hand-Held Laser Powder Fusion Welding Torch by Renteria et al. is incorporated by reference.

The laser light from the laser **160** may be delivered to the LPF Welding head **106** by a beam delivery fiber system **164** that optically transmits laser energy from the laser to the LPF Welding head **106**. Other means by which the laser energy may be delivered to the LPF Welding head **106** may also substitute for fiber optics.

The laser rangefinder head system **108** may include one or more laser range finding heads

(possibly powered in a diminished-energy mode by the laser **160**) that enable the geometrical contours of the workpiece **W** to be modeled and then coded electronically into a computer or otherwise. Alternatively, a helium-neon (HeNe) laser system may be used, as may a contact type of scanning system, along the lines of RENISHAW or other part-measuring probes to obtain the geometry of a workpiece or template part. By having a model (particularly an exact, precise, and accurate model) of the workpiece **W**, the laser powder fusion welding head **106** can then operate with exact and reliable data of the contours of the workpiece **W** that either are present or that need to be achieved via the welding process.

As can be seen in Figure 1, the laser heads **106**, **108** generally do not enjoy any horizontal or lateral degree of freedom, but are only adjustable in the vertical, z-axis direction by the z-axis linear displacement element **150** (J3 prismatic). Consequently, it becomes an operation of the support apparatus **110** with its geometrical control elements **104** to dispose the workpiece **W** in proximity to the laser rangefinding head system **108**. The laser rangefinder head system **108** can or completely determine the exterior geometry of the workpiece **W** for modeling purposes or otherwise. This is particularly advantageous when a model part is used for modeling and archiving. Such modeling is known in the art and, in summary, occurs when the rangefinding head system **108** determines the contours towards workpiece **W** as it is disposed along all three linear axes and all three rotational axes beneath the rangefinding system **108**.

All of the geometrical control elements **104** of the support apparatus **110** as well as the z linear displacement element **150** are coupled to a robot controller **170** (such as one using Adept Windows by Adept Technologies, Inc.) via digital servo amplifiers **172** or the like. This enables machine control for the linear and rotational displacement systems **104**, **150**. The robot controller **170** may also receive information signals from the laser rangefinder head system **108**, the LPF Welding head **106**, the filler material delivery system **162**, and the laser **160** via a variety of signal lines including analog/digital (A/D) signal lines and/or digital input output (DIO) signal lines. Signals are transferred and exchanged between the digital servo amplifiers **172** and the robot controller **170** subject to traffic across the connection between the two.

The degrees of freedom present in the support apparatus **110** may require the travel along two or more axes simultaneously to position the workpiece **W** properly. For example, if the workpiece **W** is rolled forward such that its top most portion now faces forward in the positive x direction, it may be necessary to decrease the displacement of the x linear displacement element **130** so that one of the laser heads **106**, **108** is directly above the former top most portion of the workpiece (prior to rotation). Such adjustments are generally easily calculated once the equations of motion are known for the support apparatus **110** and such equations may

take into account displacement of the workpiece **W** itself, not just the motion of the support apparatus **110**.

The robot controller **170** may communicate with an industrial PC (personal computer) **180** or otherwise. A number of calls, signal schemes, and/or protocols may be used in order to conduct such communication (generally two way) between the controller **170** and the PC **180**. These include: Ethernet, fast I/O, RS-485, analog T/V and PE feedback, or otherwise. Other protocols developed in the future may also be advantageously implemented in the present system **100** in order to foster, establish, maintain, provide in a robust and reliable manner the signals necessary to monitor and control the processes going on and about the workpiece **W**.

In its turn, the industrial PC may be connected to an industrial keyboard **182** which may be connected to the PC **180** via a keyboard bus **184**.

Visual monitoring of the process by transmission of video, digitized, or other sensor information can be achieved through a high-resolution or other graphics interface such as a super extended visual graphics array (SXVGA) monitor having a high-resolution display and, preferably a graphics user interface for the human machine interface (GUI HMI).

Generally, electronic control of machine elements is known in the art. However, the achievement of the present system **100** in providing a 3-D adaptive laser powder fusion welding system that both enables modeling and reconstruction/repair/manufacture of workpieces **W** provides significant advantages for LPFW Systems. The system **100** may be powered by a variety of sources with generally the following power requirements being contemplated. 120 volt AC (VAC) power generally supplies the filler material delivery system **162**. One phase 120-volt AC power generally supplies the controller **170** and the PC **180** and related systems. Three phase 208 VAC may power the digital servo amplifiers **172**. Three phase 460 VAC may power the laser **160**.

Set forth below is a possible parts list that indicates devices that may be used to achieve one embodiment of this system

Segment	Sector Name	Subsector Name	Component Name	Manufacturer
Controls				
	Computer Products	Industrial Computers	Motion Controller	Motion Engineering, Inc.
	Control Devices	Relay	Control Relay (Positive guided) General Purpose Relay Small Relay Solid State Relay	Siemens Song Chuan Phoenix Contact Omron

Segment	Sector Name	Subsector Name	Component Name	Manufacturer
Electrical	Electronic Devices	Electronic Filters	AC Line Filter	Corcom
	Operator Interface	Annunciators	Audible Alarm Mast Component	Mallory Telemecanique
		Pilot Devices	22mm Switch	Siemens
	PLC			Allen-Brady Co.
	Safety Components	Safety Components	Cable Pull Switch Guard Switch Light Curtain Safety Relay Touchswitch	Schmersal Schmersal Banner Schmersal Banner
	Sensors	Digital Sensors	Limit Switches-Mechanical Optical Sensor Proximity, Inductive	Baumer Efector, Inc. Efector, Inc.
		Sensor Accessories	Sensor Accessories	Efector, Inc.
		Sensor Cables	Sensor Cables	Efector, Inc.
	Cable & Wire	Cables	Custom Cables Data Highway Cable Ethernet Cable Flat Ribbon Cable Molded Cable Multi Conductor > 20 awg Multi Conductor High Flex Multi-Conductor < 20 awg	Cameron&Barkley Belden Anicom, Inc. Alpha L-Com Olflex Olflex Olflex
		Wire	Panel Wire	Carol
	Control Devices	Relays	Triac Relay	Omron
	Electronic Devices	Diodes	General Purpose Diode TB Diode	Newark Electronics Phoenix Contact
	Enclosures & Wiring	Conduit	Aluminum Conduit Conduit Fitting Flexible Conduit Galvanized Conduit Plastic Coat Conduit PVC Conduit Steel Conduit	Shealy Electric Wholesale Crouse-Hinds Anaconda Shealy Electric Wholesale Ocal Carlson Shealy Electric Wholesale
		Connectors	BNC Connector Circular Connector D-Sub Connector Heavy Duty Connector Interface Module Power Plug Power Receptacle Ribbon Connector	L-COM Amp Amp Harting Phoenix Contact Hubbell Hubbell Amp
		Enclosures	Climate Control Console Free-Standing Enclosure Junction Box Modular Enclosure Operator Enclosure PC Enclosure Push Button Enclosure Wallmount Enclosure	Rittal Corporation Rittal Corporation Rittal Corporation Rittal Corporation Rittal Corporation Rittal Corporation Rittal Corporation Hoffman Rittal Corporation
		Graphics	Engraved Legend Plate	Panel Graphics, Inc.

Segment	Sector Name	Subsector Name	Component Name	Manufacturer	
Electrical	Wiring	Strain Reliefs	Strain Relief	Olflex	
		Terminal Blocks	Terminal Block	Phoenix Contact	
		Wire Accessories	Cable End Cable End Marker Cable Tie Shrinkable Tubing Wire Marker Wire Terminal	Telemecanique Telemecanique Thomas & Betts Alpha Brady 3M	
		Wireduct	Wireduct (Enclosure) Fiberglass Wireway Stainless Wireway Steel Wireway	Iboco Hoffman Hoffman Hoffman	
		Motor Controls	Contactors	Contactor	Siemens
		Motor Overloads	Motor Overload	Siemens	
		Motor Starters	Motor Starter	Siemens	
		Power Distribution	Busbars	Busbar	Siemens
		Busducts	CE Busduct UL Busduct	Mempower Siemens	
		Circuit Breakers	High Trip Breaker Standard Trip Breaker	Siemens Siemens	
		Disconnects	Breaker Disconnect Fused Disconnect Knife Disconnect Rotary Disconnect	Siemens Siemens Siemens Siemens	
		Fuse Holders	DIN Rail Fuse Holder Panel Mount Fuse Holder	Gould Gould	
	Fuses	Blade-Type Fuse Cartridge Fuse Glass Fuse	Bussman Bussman Bussman		
	Distribution Blocks	Power Dist. Block	Gould		
	Power Supplies	DC Power Supply	Siemens		
	Surge Suppressors	Device Mount TB Surge Suppressor	Siemens Phoenix Contact		
	Transformers	UL Control Transformer UL Power Transformer	Hevi-Duty Acme		
	UPS	UPS	Best Power Technology		
	Mechanical				
		Conn. & Fastening	Air Service	AirLine Fittings AirLine, Plastic Fittings, SS Miniature Fittings Tubing, SS, Rigid	SMC Frelin Wade Weatherhead SMC H.M. Craig
		Mechanical Devices	Linear motion	Ball Screw Slides Belt Slides	Parker Autom Parker Autom

Segment	Sector Name	Subsector Name	Component Name	Manufacturer
Systems	Pneumatic Items	Air Preparation	Filter\Regulator\Lubricator	SMC
		Pneumatic Actuators	Cylinder & Accessories-Large	SMC
			Cylinder & Accessories-Small	SMC
			Grippers	Phd
			Pick & Place Units, > 400mm	Parker Autom
			Pick & Place Units, < 400mm	Precision Pneumatics
			Rodless Cylinders	SMC
			Rotary Actuators	SMC
			Slides & Thrusters	SMC
		Vacuum products	Vacuum Cups	SMC
			Vacuum Generators	SMC
		Valves	Ball Valves	SMC
			Flow Control Valves	SMC
	Power Transmission	Bearings/Bushings	Bearings, Ball	Various Brands
			Bearings, CamFollower	Various Brands
			Bearings, Linear, Round Shaft	INA
			Bearings, Linear, Square Rail	INA
			Bearings, Mtd, Ball	Various Brands
			Bearings, Mtd, Spherical Roller	Various Brands
			Bearings, Mtd, Takeup	Various Brands
			Bearings, Mtd, Tapered Roller	Various Brands
			Bearings, Needle	Various Brands
			Bearings, RodEnd	Various Brands
			Bushing, Composite	Various Brands
			Bushing, Spherical	Various Brands
			Bushing, Plain	Various Brands
		Hardware	Collars	Various Brands
			Clamps	Various Brands
		Motors	AC Motor up to 3 HP	US Motor
		Power Transmission	Belts, timing	Various Brands
			Belts, Vee	Various Brands
			Chain	Various Brands
			Clutches	Various Brands
			Couplings	Various Brands
			Joints	Various Brands
			Gear drives	Various Brands
			Gear Motors	Various Brands
			Sheaves, Pulleys & Hubs, Belt	Various Brands
			Sprockets & Hubs, Chain	Various Brands
		Sealing	Gaskets	Various Brands
			O-Rings	Various Brands
	Structural Products	Extrusion Accessories	Strut Accessories	Parker ParFrame
		Extrusions	Strut & Extrusions	Parker ParFrame
		Plastics	Plastic	Sheffield
Systems	Air Systems		Vacuum Generators, Large	SMC
	Conveyors	Belt/Roller Conveyors	Conveyors, Other	EASI Conveyors
			Conveyors, Custom	A&E
		Power&Free Conveyors	Conveyors, Industrial	A&E
			Conveyors, Flexible Chain	AMC
			Conveyors, Power & Free	AMC

Segment	Sector Name	Subsector Name	Component Name	Manufacturer
	Feeding Systems	Feeding Systems	Centrifugal Feeders Feeders, Other InFeed Tables/Conveyors Vibratory Feeders	VIBROMATIC VIBROMATIC VIBROMATIC VIBROMATIC
	Robotics	Robotics	Robots, Cartesian Robots, Gantry, Light & Med Servo Driven Pick & Place	Parker Autom Parker Daedal Parker Autom

While the present invention has been described with reference to a preferred embodiment or to particular embodiments, it will be understood that various changes and additional variations may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention or the inventive concept thereof. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to particular embodiments disclosed herein for carrying it out, but that the invention includes all embodiments falling within the scope of the appended claims.